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TECHNICAL MEMORANDUM

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COMPARISON OF THREE METHODS OF REMOTE METERING OF ELECTRICAL ENERGY: TELEPHONE LINE, FIBER OPTIC, AND RADIO PACKET

by

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13. ABSTRACT *(Maximum 200 words)*
This report deals with the selection of a data communication system for a remote metering system. It covers the following three types of systems: fiber optic, telephone line, and radio packet. It provides a methodology for selecting a communication system for a given remote metering system and a method for comparing costs.

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EXECUTIVE SUMMARY

This report compares three methods for remote metering of electrical energy. These three methods for connecting the remote metering points to the central station are: telephone line, fiber optic cables, and radio packets. This report provides guidance for selecting the most cost effective method for a given application, and also details costs for each method, as well as comparisons of costs of each system for different scenarios. These scenarios include the number of metering points for a given remote metering system and their distance to the central station. This report is a preliminary design tool for activities planning installation of remote metering systems.

CONTENTS

INTRODUCTION

To prevent the unnecessary use of electrical energy (for example, leaving on unneeded lights, electric ranges, large electrical motors, or other electrical devices) this use must first be located. To eliminate a high kilowatt demand which causes a utility company to buy additional and larger generating equipment, the time of such high demand must be determined so that peak-shaving or other remedial measures may be taken.

Any one of these three methods of remote metering (telephone line, fiber optic, or radio packet) can be used to transfer data on location and amount of electric power being consumed at metered points. In addition, gasoline and manhours being used to travel to remote locations to read meters can be saved by compiling kW and kWh data to one centrally-located computer.

The obvious disadvantage of remote metering is the high cost of procurement and installation of the metering system. This high cost makes it necessary to select a system which will cost the least but still provide accurate results.

PURPOSE

The purpose of this paper is to provide relative cost information and guidance for selecting between one of the three remote metering systems documented in this paper.

MATERIAL AND LABOR COSTS FOR THREE SYSTEMS

A cost comparison was made for the three systems. Table 1 provides the cost of materials, including purchasing costs, for radio, telephone, and fiber optic based systems which have 15, 32, 48, or 96 meter points at average distances of 0.6, 1, 4, and 20 miles from the central station. These numbers were derived from information which can be found in Appendices A through E.

To use this table, one must count the number of meters (points) in the system, measure their average number of miles from the central station, and enter Table 1 at these values. Where the number-of-points horizontal row intersects with the distance vertical column, the material cost for radio, telephone, and fiber optic systems can be read. If material cost is the only criteria, that system which has the lowest material cost in the block may be selected.

Table 2 shows how the cost of labor for the three systems is expected to vary with the number of meter points and their average distance from the central station. However, the cost of labor is expected to be site specific.

Table 3 provides cost of material plus labor for overall budget analysis.

Table 1. Cost of Material for Radio, Telephone, and Fiber Optic Based Systems

Distances/Points	Minimum 0.6 Miles	Short 1 Mile	Typical 4 Miles	Long 20 Miles
Small (15 points)	Radio $82,809* Phone 64,851* FO 79,422	Radio $82,809* Phone 65,251* FO 81,965	Radio $82,809* Phone 68,235* FO 111,257*	Radio $82,809 * Phone 84,173 * FO 215,697
Small (32 points)	Radio 131,715 Phone 102,206 FO 128,311	Radio 131,715 Phone 102,755 FO 131,359	Radio 131,715* Phone 106,873 FO 154,237*	Radio 131,715 Phone 128,838 FO 276,253
Medium (48 points)	Radio 177,746* Phone 137,385* FO 166,655	Radio 177,746* Phone 138,082* FO 170,211	Radio 177,746* Phone 143,244* FO 211,969	Radio 177,746 * Phone 170,864 * FO 357,730
Large (96 points)	Radio 315,838* Phone 242,889 FO 293,539*	Radio 315,838* Phone 244,019* FO 298,569*	Radio 315,838* Phone 252,348* FO 358,459*	Radio 315,838 * Phone 296,960 * FO 564,323 *

*Values from approximate equations.

Table 2. Cost of Labor for Radio, Telephone, and Fiber Optic Based Systems

Distances/Points	Minimum 0.6 Miles	Short 1 Mile	Typical 4 Miles	Long 20 Miles
Small (15 points)	Radio $103,110 Phone 56,864 FO 56,864	Radio $103,110 Phone 57,121 FO 57,121	Radio $103,110 Phone 59,052 FO 59,052	Radio $103,110 Phone 69,348 FO 69,348
Small (32 points)	Radio 219,968 Phone 121,310 FO 121,310	Radio 219,968 Phone 121,859 FO 121,859	Radio 219,968 Phone 125,978 FO 125,978	Radio 219,968 Phone 147,942 FO 147,942
Medium (48 points)	Radio 329,952 Phone 181,965 FO 181,965	Radio 329,952 Phone 182,789 FO 182,789	Radio 329,952 Phone 188,967 FO 188,967	Radio 329,952 Phone 221,913 FO 221,913
Large (96 points)	Radio 659,904 Phone 363,930 FO 363,930	Radio 659,904 Phone 365,577 FO 365,577	Radio 659,904 Phone 377,934 FO 377,934	Radio 659,904 Phone 443,826 FO 443,826

Table 3. Cost of Material and Labor for Radio, Telephone, and Fiber Optic Based Systems

Distances/Points	Minimum 0.6 Mile		Short 1 Mile		Typical 4 Miles		Long 20 Miles	
Small (15 points)	Radio	$185,919	Radio	$185,919	Radio	$185,919	Radio	$185,919
	Phone	121,715	Phone	122,372	Phone	127,287	Phone	153,521
	FO	136,286	FO	139,086	FO	170,309	FO	285,045
Small (32 points)	Radio	351,683	Radio	351,683	Radio	351,683	Radio	351,683
	Phone	223,516	Phone	224,614	Phone	232,851	Phone	276,780
	FO	249,621	FO	253,218	FO	280,215	FO	424,195
Medium (48 points)	Radio	507,698	Radio	507,698	Radio	507,698	Radio	507,698
	Phone	319,350	Phone	320,871	Phone	332,211	Phone	392,777
	FO	348,620	FO	353,000	FO	400,936	FO	579,643
Large (96 points)	Radio	975,742	Radio	975,742	Radio	975,742	Radio	975,742
	Phone	606,819	Phone	609,595	Phone	630,282	Phone	740,786
	FO	657,469	FO	664,146	FO	736,393	FO	1,008,149

COMPARISON OF MATERIAL COSTS

Table 4 shows that for proposed radio and telephone systems for 32 meter points at 0.6 miles in Pearl Harbor, Hawaii, the predicted material cost for the radio system is $131,715 and for the telephone system it is $100,903. See appendices A through E for cost determinations.

Table 4. Comparison Costs for Radio Packet and Telephone Remote Metering Systems*

Task Name	Cost for Radio Packet System	Cost for Telephone System
Material cost	$131,715	$100,903
Labor cost	219,968	121,310
Travel and per diem	23,095	11,971
Overall 1995 cost	374,778	234,184

* 32 Meter Points at 0.6 Miles at Pearl Harbor, Hawaii.

Metering systems may be high in material costs due to the requirement to provide many different kinds of metered data information (i.e., kWh, power factor, voltage, current, peak demand, etc.). To provide all this information, more circuit boards must be inserted in each meter. These circuit boards add an additional material cost to the system causing the cost to be higher.

At Pearl Harbor, Hawaii, the radio system was to provide metered data information that included kWh, power factor, voltage, current, and peak demand (Ref 1). The telephone system was to yield only kW and kWh (Ref 1).

In the case of the telephone systems, only half of the meters currently in place were to be replaced. This was because half of the meters were so old they could not be fitted with pulse initiators. The other half of the meters were new and did not require replacement.

However, in the radio systems, all the meters had to be replaced, which contributed to the higher cost.

Table 5 shows how the predicted overall radio system costs (for 32 meters at 0.6 miles at Pearl Harbor, Hawaii) would be allocated. Hardware and software, purchasing, system design, installation and training, travel, and per diem were included.

Table 5. Predicted Costs for Radio Packet Remote Metering System*

Task Name	Cost	Total
System procurement		
Cost of hardware and software	$130,393	
Cost of purchasing	1,322	
	Subtotal	$131,715
Labor		
System design	$109,906	
Installation and training	110,062	
	Subtotal	$219,968
Travel and per diem	$23,095	
	Subtotal	$23,095
Overall Radio System Cost		$374,778

* 32 Meter Points at 0.6 Miles at Pearl Harbor, Hawaii.
Installation Including Travel and Per Diem was $115,823.
Training Including Travel and Per Diem was $17,333.

Table 6 shows how the predicted overall telephone line system costs (for 32 meters at 0.6 miles at Pearl Harbor, Hawaii) were allocated. Hardware and software, purchasing, labor, per diem, rental cars, and airfare were included.

Table 6. Predicted Costs for Telephone Remote Metering System*

Task Name	Cost	Total
System procurement		
Cost of hardware and software	$99,903	
Cost of purchasing	1,000	
	Subtotal	$100,903
Labor		
996 hrs @ $79.17	$78,854	
732 hrs @ $58.00	42,456	
	Subtotal	$121,310
Travel		
Per diem	$8,036	
Rental cars	2,310	
Airfare	1,625	
	Subtotal	$11,971
Overall Telephone System Cost		$234,184

* 32 Meter Points at 0.6 Miles at Pearl Harbor, Hawaii.

Material costs for three types of 15-point systems are given in Table 7.

Table 7. Material Costs for Three 15-Point Systems*

	Material Cost for 15-point Systems		
System Type	18 Miles	19 Miles	20 Miles
Fiber Optic			$215,697
Telephone	$82,184	$83,179	84,173
Radio Packet	$82,809	$82,809	82,809

* Obtained by Summing Component Costs

The radio packet system with the lowest cost has average distances (between the points and central station) that are 19 miles or greater. When the distance is increased, the radio packet system may require no increase in material at all, whereas the telephone system and fiber optic system require an increase in their wire or cable, as well as, longer distances may require more telephone poles or fiber optic cable supports. However, in this paper we have assumed that utility poles already are in place to which the telephone wires and fiber optic cables can be attached.

The longer distance will require very little additional labor in positioning the radios, but for long distances, a substantial amount of labor may be required to install wire or cable for the telephone or fiber optic systems.

COMPARISON OF LABOR COSTS

Table 2 contains the cost of labor for the three systems. The radio system labor cost does not increase as the distance from the central station increases, if the number of meters (points) stays the same. This is because at longer distances, only the driving time to those more distant points increases; with the same number of meters (points), their setup time remains the same.

For the radio system listed in Table 2, the distance remains constant, and the labor cost increases as the number of points increase. This is true because the labor setup time is directly proportional to the number of points.

In Table 2, the labor cost for a telephone system are shown equal to the labor cost for a fiber optic (FO) system if their distances and number of points are equal. Actually, sophisticated FO connections may be difficult to make, requiring a little more labor than a simple telephone system.

CONCLUSIONS

Table 3 provides the cost of material plus labor for the three systems considered. In every block for any fixed number of points at any fixed distance, the telephone system has the lowest cost of material plus labor. This leads to the conclusion that (for the assumptions made in this paper) the telephone system will be the first choice.

However, there are situations that can significantly lower the material and/or installation costs. Example situations of lowered costs for FO and radio packet systems are provided below. The fiber optic system may be the first choice when there is a fiber optic cable currently in place serving another system, and which contains additional capacity to carry all the fiber optic metering system signals or loads. In this case, no fiber optic cable must be installed, resulting in a labor cost of approximately zero. In this scenario, the cost (material plus labor) of the fiber optic system may be less than the cost (material plus labor) of the competing telephone system and the radio system. In this case, the fiber optic system becomes the first choice.

As an example:

The number of points	=	48
The distance	=	4 miles
For the radio system:		
(material plus labor)	=	\$507,698
For the telephone system:		
(material plus labor)	=	\$332,211

For the FO system: (with cable in place)

material	=	<$211,969
labor	=	0
(material plus 0 labor)	=	$211,969
Fiber optics $211,969	<	Radios $507,698
Fiber optics $211,969	<	Telephones $332,211

The fiber optic system is first choice when the FO cable is already in place.

Next, consider a situation where the radio packet system may be the first choice. Table 7 shows the radio packet system has the lowest material cost for a 15-point system at distances of 19 miles and above.

Table 3 and a graphical method were used to calculate the data provided in Table 8, which shows material plus labor costs for 15 point systems. The graphical method utilized is very similar to Figure 1 shown in Appendix C.

Table 8. Material and Labor Cost for Three 15-point Systems*

	Material Plus Labor Cost for 15-Point System			
System Type	20 Miles	40 Miles	41 Miles	60 Miles
Fiber Optic	$285,045	$428,600	$436,000	$573,500
Telephone	153,521	185,919	187,600	218,300
Radio Packet	185,919	185,919	185,919	185,919

* 15-point systems at 20, 40, 41, and 60 miles.
Telephone system and FO system amounts were obtained by graphical methods.

Table 8 shows the costs (material plus labor = $185,919) are the same for both the telephone system and the radio packet system at a distance of 40 miles. However, for distances of 41 miles or greater, the radio packet system has a lower cost than either the telephone or fiber optic systems.

Another factor that may alter the system choice is the life cycle cost. When maintenance and repair costs are considered in addition to material and labor costs, the lowest cost system may not be the first choice.

A February 1995 publication, (Ref 2), prepared for the U.S. Army Corps of Engineers at Huntsville, Alabama, states, "FO cable assemblies, including jacketing and fibers, shall be certified by the manufacturer to have a minimum life of 30 years." However, the article does not specify the lifetime of FO transmitter and receiver modules, FO modems, transceiver modules, repeaters, and connectors. Although the FO cable has a 30-year life, communication professionals claim the life of an entire FO communication system is about 20 years.

Telephone experts claim that the life of a telephone system is also about 20 years. When asked what the lifetime of a radio is, most radio professionals answered that the guarantee on a radio is between 90 days and 2 years. The guarantee on the Spirit III, two-way Motorola radio is 2 years; hopefully, its lifetime will be greater than its guarantee.

RECOMMENDATIONS

Component lifetimes and guarantees should be determined for each system prior to selecting a radio packet, fiber optic, or telephone line system for remote metering. An entire system may fail to operate if only one component stops functioning. Many of the systems are so sophisticated that repairs become very expensive.

Investigating the possibility of attaching telephone cables to utility poles which are currently in place is recommended for installation of telephone line systems.

Investigation should be done at the site to determine the capabilities of existing fiber optic systems. This investigation will determine whether or not the remote metering system can be tied to the fiber optic system, thus lowering installation costs.

REFERENCES

1. Naval Civil Engineering Laboratory. Proposal for remote metering at public works center, Pearl Harbor, HI. Port Hueneme, CA, April 1991.

2. Kling-Lindquist Partnership, Inc. Energy management system components with installation, maintenance, and service, revised specifications. Huntsville, AL, Feb 1995.

Appendix A

ONE MATERIAL COST APPROXIMATION

In Table 1 of the main text, the material cost values marked with an asterisk have been found by using approximations or assumptions. For example, the radio packet system with 48 meter points at one mile has an asterisk on $177,746 because this value was found by assuming that each meter which is added to the system (after the first meter) caused the system cost to increase by exactly the same amount as long as the average distance (between meters and the central station) remains the same. In other words, as long as this distance is 1 mile, if the addition of a second meter caused the system cost to increase by $2,000, then the addition of the tenth meter would also cause the system cost to increase by $2,000. If 8 meters were added, the system cost would increase by (8 x $2,000) = $16,000.

As an illustration of the above approximation, to find the cost of material for a radio packet system with 15 meter points at one mile from the central station, locate the material cost for a radio packet system which has only one remote meter at 1 mile. This cost is found in Table 1 shown below to be $42,532. Next, find the material cost for a radio remote metering system which has 32 meter points at 1 mile from the central station. Table 2 gives this cost as $131,715.

Table 1. Material Cost for Radio Packet Remote Metering System*

Quantity	Part	Price
1	PRC (with battery backup)	$1,530
1	Electronic meter (3-phase)	517
1	Radio head-end workstation (includes software and 2 PRC head-end masters)	32,211
1	Meter (3-phase) spare	517
1	PRC spare (with battery backup)	1,530
1	PRC Head-end master spare	1,530
2	Portable Laptop PC computers (for PRC programming and PWC field work). These include PRCs and software	3,039
1 Lot	Installaion material (meter boxes, dual socket adapters, conduit, wire, and miscellaneous hardware)	570
Cost Without Purchasing		$41,444
Purchasing		$1,088
Material Cost for 1 Meter System		$42,532

* One remote meter (point) at 1 mile

Table 2. Material Cost for Radio Packet Remote Metering System*

Quantity	Part	Unit Cost	Cost
32	PRC (with battery backup)	$1,454	$46,528
32	Electronic meters (3-phase)	517	16,544
1	Radio head-end workstation (includes software and 2 PRC head-end masters)	32,211	32,211
4	Meters (3-phase) spare	517	2,068
4	PRC spares (with battery backup)	1,454	5,816
2	PRC Head-end master spares	1,454	2,908
2	Portable Laptop PC computers (for PRC programming and PWC field work). These include PRCs and software	3,039	6,078
32 Lots	Installation material (meter boxes, dual socket adapters, conduit, wire, and miscellaneous hardware)	570	18,240
Cost Without Purchasing			$130,393
Purchasing			$1,322
Total Material Cost			$131,715

* 32 meters (points) at 1 mile

For a 32-meter system,

$$\text{(cost for 32 meters)} = \text{(cost for first)} \div \text{(cost for last 31)}$$

$$\text{(cost for last 31)} = \text{(cost for 32 meters)} - \text{(cost for first)}$$

$$\text{For last 31: } \left(\frac{\text{cost}}{\text{meter}}\right) \text{(31 meters)} = \$131{,}715 - \$42{,}532$$

$$\text{For last 31: } \left(\frac{\text{cost}}{\text{meter}}\right) = \frac{\$131{,}715 - \$42{,}532}{31}$$

$$\text{For last 31: } \frac{\text{cost}}{\text{meter}} = \$2{,}876.87 \approx \$2{,}876.9$$

For our problem of finding the cost of material for a radio packet system which has 15 meter points at 1 mile, we assume that:

$$\text{For last 14: } \frac{\text{cost}}{\text{meter}} = \frac{\text{cost}}{\text{meter}} \text{ for last 31 found above}$$

For last 14: $\frac{\text{cost}}{\text{meter}}$ = \$2,876.9

$$\text{Cost for 15 points} = (\text{cost of 1st point}) + (\text{cost of last 14})$$

$$= (\$42{,}532) + (14 \text{ points}) \left(\frac{\text{cost}}{\text{meter}} \text{ for last } 14 \right)$$

$$= (\$42{,}532) + (14)\ (\$2{,}876.9)$$

$$= \quad \$82{,}809^*$$

The asterisk signifies that the material cost of \$82,809 was found by the approximate method illustrated. This material cost also has an asterisk at the 15-point, 1-mile position for the radio system in Table 1 of the main text.

For the above case, the general equation for the material costs, C_P, for a system with P points (or meters) is Equation 1:

$$C_P \quad = \quad \$42{,}532 + (P\text{-}1)\ (\$2{,}876.90) \tag{1}$$

Equation 1 was also used to find the material cost for a radio system having 48 points at 1 mile as follows:

$$P = 48$$

$$C_{48} = 42{,}532 + (47)\ (2{,}876.9)$$

$$C_{48} = \$177{,}746^*$$

This value is found in Table 1 of the main text.

We can use Equation 1 again to find the material cost for a radio system having 96 points at 1 mile, as follows:

$$P = 48$$

$$C_{96} = 42{,}532 + (95)\ (2{,}876.9)$$

$$C_{96} = \$315{,}838^*$$

This value is also found in Table 1 of the main text.

All the other radio system material costs for a fixed number of points are the same for any distance between the points and the central station. Thus, $315,838 for 96 points can be entered in Table 1of the main text in the 0.6, 1, 4, and 20-mile blocks. Also, $177,746 for 48 points can be entered in Table 1 of the main text in the 0.6, 1, 4, and 20-mile blocks.

The only other material costs in Table 1 of the main text that contain an asterisk are for the fiber optic system with 96 points, found in the bottom-most row of this table. These were determined by the similar-triangle approximation method illustrated in Appendix C.

All the material cost values in Table 1 of the main text that do not have an asterisk were found by simply summing all the costs of the individual components.

Appendix B

A SECOND MATERIAL COST APPROXIMATION

In Table 1 of the main text, the material costs for fiber optic systems with 15, 32, and 48 points at distances of 0.6, 1, 4, and 20 miles were found by first producing a preliminary design of each system. The price of each component in a system was obtained from various venders. These component prices were then summed to obtain the material cost of the complete fiber optic system. The system's material cost was then entered in Table 1.

After entering the fiber optic material costs for the distances above into Table 1, the remaining costs to be entered were those for systems with 96 points at distances of 0.6, 1, 4, and 20 miles from the central station. For these 96-point systems, a preliminary design was not produced. Material costs were not obtained by summing the prices of the components because the preliminary design produced might not be the lowest-cost design possible.

To obtain the 96-point, fiber optic system material costs in the bottom row of Table 1, a similar-triangle approximate method was used. This method could also be called an extension-of-a-line graphical method. The method will be illustrated by using it to solve the following problem:

PROBLEM:

Find the material cost of a fiber optic system having 96 points at 4 miles from the central station.

GIVEN:

In Table 1 the fiber optic system material cost for 15 points at 4 miles was listed as \$111,257. Table 1 also lists the fiber optic system material cost for 48 points at 4 miles as \$211,969.

SOLUTION:

Near the bottom of a page we first draw a horizontal line. Using an appropriate scale, the left end of the line is marked 15 points, the right end is marked 96 points, and again using the appropriate scale, a point between ends is marked 48 points (see Figure 1).

From the 15-point location, a vertical line is drawn upward to scale to a point which represents \$111,257. From the 48-point location, a vertical line is drawn upward to scale so that it represents \$211,969. From the 96-point location, a line is drawn vertically upward.

A line is drawn from the 15-point location ($111,257) to the 48-point location ($211,969), and this line is continued upward and to the right until it intersects the vertical line drawn upward from the 96-point location. Using the appropriate scale, this intersection is at $358,459.

ANSWER: $358,459 is the answer to the problem.

Appendix C

THE SIMILAR-TRIANGLE SOLUTION FOR COSTS

Graphical methods cannot be expected to give accuracy to six significant figures. For greater accuracy, the similar-triangle method can be used. The rule is: the sides of similar triangles are proportional. From similar triangles in Figure 1:

$$\frac{B}{A} = \frac{C}{A + D}$$

$$\frac{100{,}712}{33} = \frac{C}{33 + 48}$$

$$\frac{100{,}712}{33} = \frac{C}{81}$$

$$33C = (81)(100{,}712)$$

$$C = \frac{(81)(100{,}712)}{33}$$

$$C = 247{,}202$$

$$C + E = 247{,}202 + 111{,}257$$

$$C + E = \$358{,}459$$

ANSWER: The material cost of a fiber optic system having 96 points at 4 miles is $358,459.

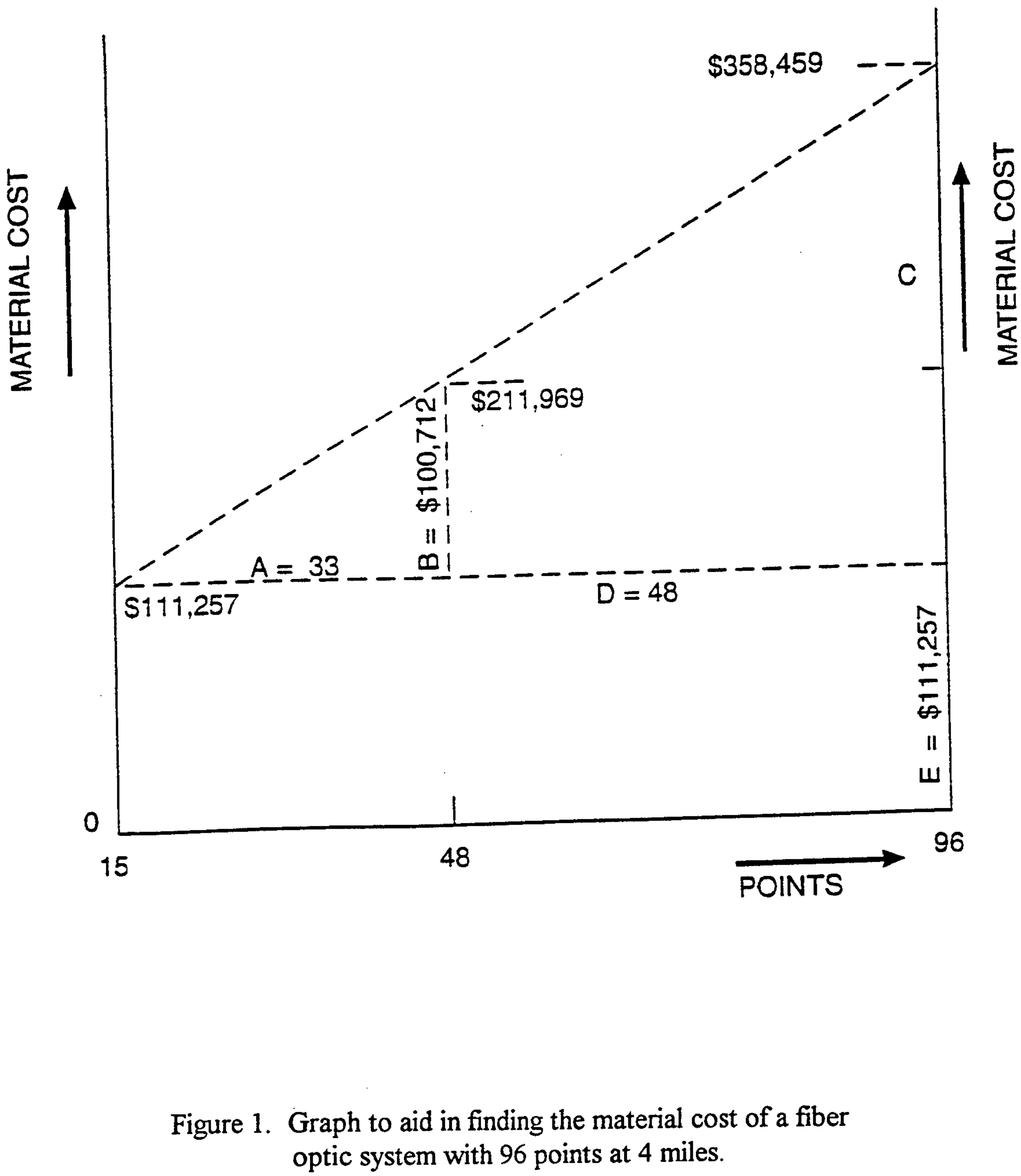

Figure 1. Graph to aid in finding the material cost of a fiber optic system with 96 points at 4 miles.

Other entries in Table 1 (shown in the main text) for the fiber optic systems with 96 points at 0.6, 1, and 20 miles were found by the similar-triangle method.

Equation 2 was used to obtain the material costs found in Table 1 for telephone based systems:

$$\text{Material Cost} = \begin{pmatrix}\text{cost of} \\ \text{1 pt system}\end{pmatrix} + \left(\frac{\text{cost}}{\text{pt}}\right)\begin{pmatrix}\text{number of pts} \\ \text{after the 1st pt}\end{pmatrix} \tag{2}$$

Thus, the cost of one-point systems must be found. These costs were obtained by summing all the component prices in each of these one-point systems. In Table 1 (see page C-4), the summation of the component prices for a 1-meter, 4-mile system is shown.

To connect the head-end station's modem to the meter's modem which is 4 miles away, we need 4 miles of full duplex telephone cable as in Figure 2. This cost is listed in Table 1.

$$\text{Cable cost} = 4 \text{ miles} \times \frac{5{,}280 \text{ ft}}{\text{mile}} \times \frac{\$.13}{\text{ft}}$$

$$\text{Cable cost} = \$2{,}746$$

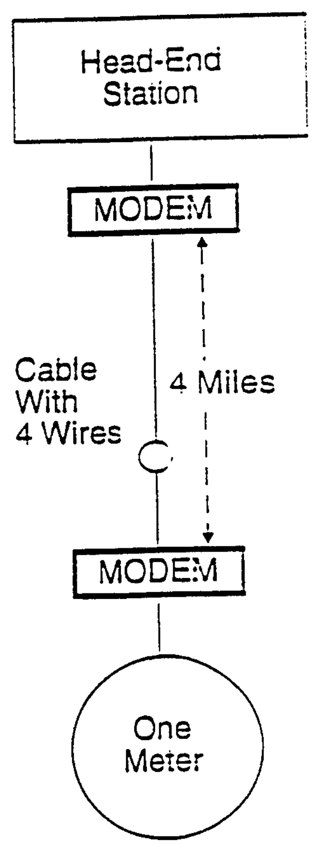

Figure 2. System with one meter at 4 miles.

Table 1. Hardware and Software Total Costs for Telephone-Pulse Metering System*

Quantity	Part	Costs
1	Computer system with telephone modem 9600 BAUD OPTIMA 96 to be used at the central station.	$7,293
1	Data acquisition software lot	21,271
1	Electronic recording device. This is at the 1 meter (point) site. It encodes pulse signals into data. It contains a telephone modem.	1,216
1	New meter with pulse initiator to replace old meter that can't use pulse initiators.	912
0	Electronic pulse initiators to be put into newer meters that can be fitted with pulse initiators.	---
1	LOTS of misc.electrical components	77
1	Full duplex cable for one point; 1 mile = 5,280 ft. 4 miles is 21,120 ft x $\frac{.13}{\text{ft.}}$ =	2,746
1	Spare electronic recording device.	1,216
1	Spare new meter with a pulse initiator.	912
Purchasing Cost		770
Total Cost		$36,413

* 1 meter (point)at 4 Miles

The sum of all the costs of a 1 meter (point) system at 4 miles is $36,413. This $36,413 is entered in the top row of Table 2 (see page C-7) under 4 miles.

For the telephone system, using the same summing method for the 1-point, 4-mile system, we find the sum of all components for a 1-point, 0.6-mile system is $34,079; for a 1-point, 1-mile system, the sum is $34,353; for a 1-point, 4-mile system, this sum was found previously as $36,413; for a 1-point, 20-mile system, it is $47,395. These values are all entered in the top row of Table 2.

Next, in the equation:

$$\text{Material cost} = \left(\begin{array}{l}\text{cost of}\\ \text{1 - pt system}\end{array}\right) + \left(\frac{\text{cost}}{\text{pt}}\right)\left(\begin{array}{l}\text{number of points}\\ \text{after the first pt}\end{array}\right)$$

we need to find the $\frac{\text{cost}}{\text{pt}}$ of all points besides the 1st point where the

$$\frac{\text{cost}}{\text{pt}} = \left(\frac{\text{cost due to points added to the 1st pt}}{\text{number of points added after the 1st pt}}\right)$$

$$\frac{\text{cost}}{\text{pt}} = \left(\frac{\text{cost of entire system } - \text{ (1st pt)}}{\text{number of pts added to the 1st pt}}\right)$$

The cost of the first point has already been found; the cost of the entire system is needed.

The material costs for an entire 32-point telephone system can be found by adding the costs of wire and modems to the Pearl Harbor estimate. Once obtained, the cost of 32-point systems are to be entered on the second row of Table 9 in the appropriate distance column.

For an entire 32-point telephone system at 4 miles with points arranged in a circle, as in Figure 3, it was assumed only two 4-mile full duplex cables to reach out to the vicinity of the points would be needed. Due to multiplexing, the wire needed at the points is negligible.

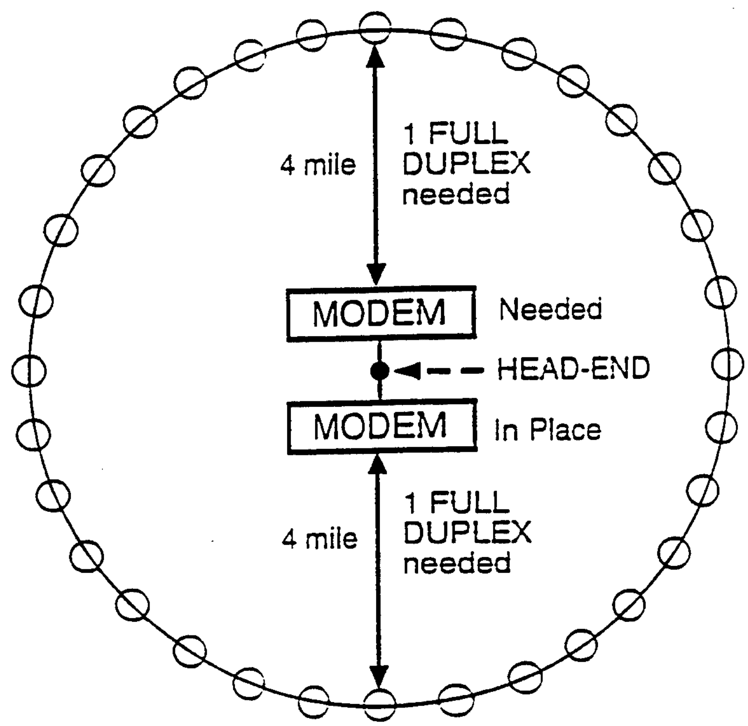

Figure 3. A 32-point, 4-mile telephone system.

To obtain the material cost for a 32-point system at 4 miles, we sum the following:

Pearl Harbor cost without the necessary modem and wire	=	\$100,903
Cost of 1 modem	=	479
Cost for 8 miles of full duplex cable 8 miles x $\frac{5{,}280 \text{ ft}}{1 \text{ mile}} \text{ X } \frac{\$0.13}{\text{ft}}$	=	5,491
Material cost for 32-point telephone system at 4 miles	=	\$106,873

Thus, \$106,873 is entered in the second row in Table 9 for a 32-point system at 4 miles.

The other entries in the second row of Table 2, labeled Phone, were found exactly as the \$106,873 above. Simply sum \$100,903 + (the cost of a needed modem) + the cost of needed wire for the distances 0.6 mile, 1 mile, and 20 miles. The sums are entered in the second row of Table 2 under the appropriate distances as \$102,206, \$102,755, and \$128,838.

From above, we already know:

$$\frac{\text{cost}}{\text{pt}} = \frac{\text{cost due to points added to the 1st pt}}{\text{number of points added after the 1st pt}}$$

The cost per point for the last 31 points was found from the equation:

For last 31 points:

$$\frac{\text{cost}}{\text{pt}} = \frac{\text{cost of 31 pts}}{31}$$

$$\frac{\text{cost}}{\text{pt}} = \frac{(\text{cost of 32 - pt system}) - (\text{cost of 1 - pt system})}{31}$$

At 0.6 mile this becomes:

For last 31 points:

$$\frac{\text{cost}}{\text{point}} = \frac{\$102{,}206 - \$34{,}079}{31}$$

$$\frac{\text{cost}}{\text{point}} = \$2{,}198$$

At 1 mile this becomes:

For last 31 points:

$$\frac{\text{cost}}{\text{pt}} = \frac{\$102{,}755 - \$34{,}353}{31}$$

$$\frac{\text{cost}}{\text{pt}} = \$2{,}207$$

At 4 miles:

For last 31 points:

$$\frac{\text{cost}}{\text{pt}} = \frac{\$106{,}873 - \$36{,}413}{31}$$

$$\frac{\text{cost}}{\text{pt}} = \$2{,}273$$

At 20 miles:

For last 31 points:

$$\frac{\text{cost}}{\text{pt}} = \frac{\$128{,}838 - \$47{,}395}{31}$$

$$\frac{\text{cost}}{\text{pt}} = \$2{,}627$$

All of these values (cost/point) are entered on the third line of Table 2.

Table 2. Material Cost

Distances/ Orig. Points	Minimum 0.6 Mile	Short 1 Mile	Typical 4 Miles	Long 20 Miles
Phone: Cost of 1-point system	$34,079	$34,353	$36,413	$47,395
Phone: Cost of 32-point system	102,206	102,755	106,873	128,838
Cost/Point for last 31 points	2,198	2,207	2,273	2,627

How to determine the material costs entered in Table 1 of the main text for the telephone system follows:

Consider the telephone system with 15 points located an average of 0.6 miles from the central station. Assume that the cost of a one point system for this 15 point, 0.6 mile system is the same ($34,079) as it was for a 1 point system for the 32 point, 0.6 mile system, and also assume that the cost/point of the last 14 points in the 15-point, 0.6-mile telephone system is the same ($2,198) which was the cost/point of the last 31 points in the 32 point, 0.6 mile system.

For the 15-point, 0.6-mile telephone system:

$$\begin{aligned}\text{Material cost} &= \text{cost of 1 point system} + \text{cost of adding 14 points} \\ &= \text{cost of 1-point system} + \left(\frac{\text{cost}}{\text{pt}}\right)(14 \text{ pts}) \\ &= \$34{,}079 + (\$2{,}198)\,(14) \\ &= \$64{,}851\end{aligned}$$

This $64,851 is entered in Table 1 in the 15-point, 0.6-mile block for the telephone system.

For completeness, one more material cost will be determined. Consider the telephone system with 96 points located an average of 20 miles from the central station. We assume that the cost of a one-point system for this 96-point, 20-mile system is the same ($47,395) as it was for a 1-point system for the 32-point, 20-mile system.

We also assume that the cost/point for the last 95 points in the 96-point, 20-mile telephone system is the same ($2,627) which was the cost per point of the last 31 points in the 32-point, 20-mile system.

For the 96-point, 20-mile, telephone system:

$$\text{Material cost} = \text{cost of 1 - pt system} + \text{cost of adding 95 pts.}$$

$$= \text{cost of 1 - pt system} + \left(\frac{\text{cost}}{\text{pt}}\right)(95 \text{ pts})$$

$$= \$47{,}395 + (\$2{,}627)(95)$$

$$= \$296{,}960$$

This $296,960 is entered in Table 1 of the main text in the 96-point, 20-mile block for the telephone system.

Appendix D

MATERIAL COSTS OBTAINED BY SUMMING COMPONENT COSTS

In Table 1 of the main text, if a material cost value has no asterisk, this indicates that the cost was obtained by first finding the cost of each component in the system and then adding the costs of all the components. An example is shown in Table 1 below. The sum ($211,969) found in Table 1 below is entered in Table 1 of the main text without an asterisk for the fiber optic system with 48 points at 4 miles.

Table 1. Materials Cost Estimate for Fiber Optic Remote Metering System*

Quantity	Description	Total
1	Computer hardware set	$7,147
1	Software set	21,271
48	Electronic recorders @ $1,216	58,368
24	Meters with pulse initiators @ $912	21,888
24	Pulse initiators @ $425	10,200
2	Muxes 48-to-1 @ $1,400	2,800
14	Line drivers @ $1,200	16,800
48	Telephone modems @ $479	22,992
	Duplex cable	35,595
	Miscellaneous supplies	3,696
4	Spare recorders @ $1,216	4,864
4	Spare new meters with pulse initiators @ $912	3,648
4	Spare pulse initiators @ $425	1,700
	Purchasing	1,000
Total Material Cost		$211,969

* 48 Meters (points) at an average distance of 4 miles from the central station

Appendix E

COST ESTIMATES FOR A PEARL HARBOR SYSTEM

Telephone line and radio packet remote metering at Public Works Center, Pearl Harbor, Hawaii was discussed in Reference 1. The Pearl Harbor system was planned to have 32 meters (points) at an average distance of about 0.6 miles from the central station.

The proposal estimated the overall radio packet system cost as $301,056. Utilizing a cost of living increase of 5% per year and some known prices, the estimated system cost had risen to $374,778 as given in Table 1.

The same paper (Ref 1) estimated the overall telephone line system cost in the Pearl Harbor area as $179,051. Increasing this figure by 5% per year and using some current prices, the total costs are $234,184, also given in Table 1.

Table 1. Comparison of Estimated Prices for Two Systems*

Task Name	Radio Packet System	Telephone Line System
Procurement	$131,715	$100,903
Labor	$219,968	$121,310
Travel	$23,095	$11,971
Total Cost	$374,778	$234,184

Each system consists of 32 meters at an average of 0.6 miles from the head-end station at Pearl Harbor

The estimated system cost in Table 1, i.e., $374,778 for the radio packet system and $234,184 for the telephone line system, give the impression that the radio packet system will in all cases be more expensive than the telephone line system. This is not always the case; there are specific sites or situations where the radio packet system does, in fact, have a lower system cost than the telephone line system.